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14. ABSTRACT
Describes procedures for evaluating the cold-staring capability of military engines with and without the aid of arctic-kit engine heaters.

15. SUBJECT TERMS

Arctic tests	Low temperature
Cold starting	Vehicle, warm-up
Engine, cold starting	Vehicles, tracked
Engine, heaters	Vehicles, wheeled

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US ARMY DEVELOPMENTAL TEST COMMAND
TEST OPERATIONS PROCEDURE

*Test Operations Procedure 2-2-650 12 February 2008
DTIC AD No.

ENGINE COLD-STARTING AND WARM-UP TESTS

*This TOP supersedes TOP 2-2-650, 18 July 1980.

1. SCOPE.

a. This TOP provides procedures for evaluating the cold-starting capability of military engines with and without the aid of arctic-kit engine heaters. Tests are usually conducted in conjunction with vehicle low-temperature tests (TOPs 2-2-816[1**] and 2-2-708[2]).

b. These TOPs will be utilized by Department of Defense Developmental Test Centers to include but not limited to Aberdeen Test Center (ATC), Cold Regions Test Center (CRTC), and Yuma Test Center (YTC) for conducting cold-start and warm-up tests.

2. FACILITIES AND INSTRUMENTATION.

2.1 Facilities.

2.1.1 Chamber Climatic Tests. A temperature chamber for conditioning the vehicle to temperatures ranging from -18 degrees to -51 degrees C (0 degrees to -60 degrees F).

2.1.2 Outdoor Low-Temperature Tests.

a. A heated enclosure for preparing the vehicle for testing.

b. A heated enclosure to house instrumentation.

2.2 Instrumentation.

ITEM	MAXIMUM ERROR OF MEASUREMENT*
Temperature sensors and recorder	±2.0 degrees C (3.6 degrees F)
Battery hydrometer	Specific gravity to ±0.005
Voltmeter	±3% of full scale
Ammeter and shunt	±3% of full scale
Tachometer	±10 rpm (for cranking speed)
Pressure gauges (as appropriate)	±1 psi
Data logger, or other device, to record voltages and current during cranking period	Sample Rate: 1000 Hertz

*Values may be assumed to represent ±2 standard deviations. Thus, the stated tolerances should not be exceeded in more than 1 measurement out of 20.

a. The sample rate recommended in the instrumentation table is quite high at 1000 Hz. This is based on historical data regarding the response rate of various engine components to an engine start event, in particular the rate of change of electrical current draw. The primary purpose of this recommended high sample rate is to ensure no aliasing of the test data and that peaks within the data consist of multiple data points. If instrumentation availability is limited then sample

** Superscript numbers correspond to those in Appendix D, References.

rates may be reduced, so long as the necessary data channels show no signs of aliasing at the lower rate. However, this may not be observed until the test is underway, at which time changing the instrumentation is difficult.

b. This high sample rate is only required for periods of engine cranking. Conditioning and temperature monitoring can be done at a much lower sample rate such as 1 Hz. This is often done by using two separate data recording devices.

3. REQUIRED TEST CONDITIONS.

3.1 Vehicle and Test Preparations.

a. Ensure that initial inspection and preliminary operation of the vehicle have been accomplished in accordance with TOP 2-2-505[3].

b. Prepare the test vehicle for cold-weather operation in accordance with the vehicle technical manual (TM) and FM 9-207[4] (e.g., arctic antifreeze is installed in the cooling systems and artic lubricating and gear oils installed in other systems as prescribed in the lubrication order for cold-weather operations). Component fluids should be drained and refilled with the appropriate lubricant specified in the TM. Flushing of components is not recommended unless included in the TM procedures, as this is not normally performed in the field.

c. Battery testing is required prior to negotiating any climatic testing. Verify that each battery is fully charged prior to any inspection. Refer to manufacturer or TM instructions on testing or recharging batteries prior to proceeding with other methods of battery preparation. There are various types of batteries that require different cold temperature preparations (refer to TM for procedures). Each battery listed below requires specific charging/preparation instructions (refer to each respective TM for cold temperature preparation):

(1) The starting battery is designed to deliver quick bursts of energy (such as, engines that require high torque starters) and has a greater plate count. These plates will also be thinner and have somewhat different material composition than the other types of batteries.

(2) The deep cycle battery has less instant energy but greater long-term energy delivery. Deep cycle batteries have thicker plates and can survive a number of discharge cycles.

(3) A Gel or Gelled Acid battery is just a “non spill” version of the normal Sulfuric Acid battery. Silica Gel crystals are added or dissolved into the Acid to form a paste or Gel to stop the Acid being a liquid.

(4) AGM batteries which still use Acid, but in this case cannot spill because the acid is Absorbed (A) into Glass (G) Mat (M). These offer more cycles, greater performance whether Deep cycle or Starter types.

d. Check the battery for correct voltage and specific gravity (in each cell) if possible. Batteries are considered fully charged when the specific gravity of the electrolyte is higher than 1.260. The ranges from 1.230 to 1.260 constitute a three-quarter charge.

(1) TM 9-6140-200-14[5] should be utilized for battery charging and State of Charge (SOC) determination for other types of batteries.

(2) For sealed batteries many are equipped with an "eye" that depending on the color observed will indicate the battery's state of charge. In addition to observing the "eye", a digital volt meter should be used to measure the battery voltage. If the battery had recently been charged, the surface charge must be removed and that can be accomplished by turning on an accessory (headlights, parking lights, etc.) for a few minutes. A fully charged battery will have a static voltage of 12.6 volts at room temperature. All battery checks should be performed at room temperature.

(3) Table 1 represents a correlation between specific gravity and battery voltage for a standard lead acid battery.

TABLE 1. Specific Gravity and Battery Voltage Requirements

STATE OF CHARGE	SPECIFIC GRAVITY	BATTERY VOLTAGE
100%	1.265	12.6
75%	1.225	12.4
50%	1.190	12.2
25%	1.155	12.0
Discharged	1.120	11.9

e. In addition to prepping the test item's batteries, it is recommended that a spare set be prepped and placed in the chamber. This will allow both the vehicles and the spare set to reach temperature stabilization. Batteries should initially be charged at room temperature or below, and charged prior to being put back in service unless TM or manufacturer instruct otherwise. The batteries need to be warmed up to approximately room temperature before attempting to charge. Cold batteries do not accept charge as well as warm batteries and will not return to full SOC at the lower test temperatures. Batteries should *not* be stored in a discharged state. A visual inspection must be performed on each battery to detect the following:

(1) Low electrolyte level (non-sealed batteries),

(2) Corroded battery terminals,

(3) Swollen or corroded battery cables,

(4) Loose battery terminals or hold.

3.2 Engine Heaters.

a. Inspect the heaters and other winterization kit components for equipment discrepancies, damage, or missing parts. If damage has been sustained, obtain authorization and make repairs when possible.

b. Install the heater and other kit components on the vehicle in accordance with the instructions provided in the kit.

c. Prior to conditioning the test item, operate heater at ambient temperature for a minimum of 1 hour (may require overriding temperature sensor) to ensure that any air is purged and any fuel (for fuel fired heaters) has been cycled through.

3.3 Temperature Chamber.

a. Position the vehicle in the test chamber so that:

(1) Air circulation is not impaired.

(2) Critical vehicle elements are accessible for inspection and operation.

(3) Clear and easy access is provided to personnel operation areas.

(4) Where possible, personnel can be seen through the chamber observation windows.

b. Install ducts to remove vehicle and engine heater exhaust fumes from the chamber, as shown in Figure 1 below. Fabricate adapters (larger diameter exit) in order to prevent exhaust cavitation.

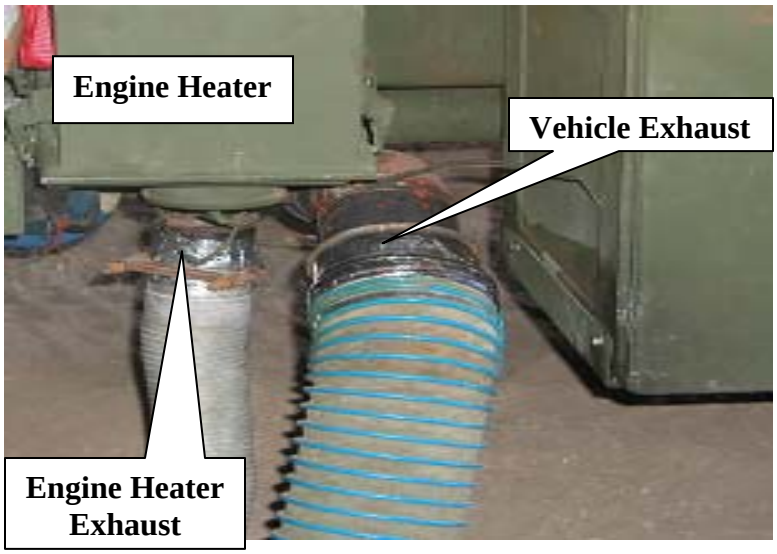

Figure 1. Set-up of ducts to remove fumes from a test chamber.

c. All necessary safety precautions such as video cameras and toxic fume monitoring devices in the climatic chamber are recommended.

3.4 Test Controls.

Do not conduct test when there is a large change in chamber air temperature. Temperature variation during the test should be kept to a minimum to ensure consistency and accuracy of results. This is typically not a problem during the actual engine start attempt which is quite short, or during engine preheat periods as waste heat output into the chamber is commonly quite low. It is desirable to keep temperature fluctuations within ±2 degrees C (± 3.6 degrees F) of the target test temperature, per MIL-STD-810F[7]. The greatest care must be taken to monitor this parameter during periods where the vehicle engine is running while in the chamber, such as during Engine Heater Standby testing. If temperature changes by more than a maximum of +5 degrees C (+9 degrees F) during test, repeat the test.

4. TEST PROCEDURES.

4.1 Cold Starting without Engine Heater. This test determines the temperature at which the vehicle can be started without external aids by repeating the procedure below at temperatures of -18 and -32 degrees C (0 and -25 degrees F), unless otherwise specified. Successful starts are obtained at the higher temperature before proceeding to the lower test temperature.

4.1.1 Method.

a. Cold soak the vehicle at the test temperature for a minimum of 8 hours after all components have stabilized to within 2 degrees C (3.6 degrees F) of the test temperature. When applicable, use cool-down blowers to facilitate equipment cold soaking. Use fully charged cold-soaked batteries for each cold-start attempt.

b. Make the first start attempt of the vehicle using the instructions in the TM. If not in adequate detail, use the appropriate starting techniques in Appendix B for compression-ignition engines or in Appendix C for turbine engines.

NOTE: A successful start is defined as a start of a cold-soaked vehicle without any external assistance (slave starting, starting aids not part of the vehicle).

c. An engine start attempt consists of cranking attempts until the engine starts with a single set of batteries. If batteries maintain adequate voltage for cranking the engine, multiple cranks can be performed and will be considered a successful start. In the event the engine does not start and the batteries are depleted, an attempt to start the engine by external slaving or other means should be performed to determine if the engine is capable of operation in the test temperature. If it is possible to slave start the engine, a second attempt at starting the engine after soaking the vehicle should be performed on fully charged batteries.

d. Whenever the engine starts, allow it to run for 15 to 20 minutes to reach normal operating temperatures. After the engine has stabilized, it should be checked for throttle response and proper operation. If it is not possible to start with one set of batteries, it may be necessary to start the vehicle by slaving, warming, or other appropriate means to purge unburned fuel. Consult the applicable TM for the necessary procedures to follow upon a failed cold start attempt. Repeat the starting attempt after sufficient soaking time is allowed to recondition the engine and allow temperatures to re-stabilize.

e. After engine start at -32 degrees C (-25 degrees F), evaluate personnel heater and defroster as outlined TOP 2-2-708, if this is part of the test program.

4.2 Cold Starting with Engine Heater.

4.2.1 Method.

a. Cold soak the vehicle at -46 degrees C (-50 degrees F) to satisfy the cold (C2) condition of AR 70-38[6], unless otherwise specified. (The severe-cold (C3) condition of -51 degrees C (-60 degrees F) may also be required.) Soak the vehicle for at least 8 hours once all components are within 2 degrees C (3.6 degrees F) of the test temperature. When applicable, use cool-down blowers to facilitate equipment cold soaking.

b. Start the engine heater and monitor the engine oil (sump) and coolant temperatures. When the engine oil reaches the starting temperature specified in the test directive, or -32 degrees C (-25 degrees F) if not specified, turn off the heater and attempt to start the engine using the technique of paragraph 4.1.1.b. If the engine fails to start, the procedures contained within the TM should be followed. If the engine still fails to start, repeat the test increasing the preheat time in half-hour increments until the engine starts or 2 hours of preheat time is accumulated.

c. Once the preheat period has been determined, follow procedures of paragraph 4.1.1.c.

4.3 Engine Heater Standby Test.

4.3.1 Method.

a. Following a cold start at -51 degrees C (or other required temperature), operate the engine until the temperature of the coolant (for liquid cooled engines), the cylinder head (for air cooled engines), or the oil temperature in sump (for turbine engines), stabilizes, and then shut down the engine.

b. Start and operate the engine heater in the standby mode.

c. Record the following every hour, and terminate standby operations when temperatures stabilize or after 24 hours. Stabilization is attained when the temperature of the item with the longest thermal lag is changing at a rate of no more than 2.0 degrees C (3.6 degrees F) per hour (from MIL-STD-810F[7]).

(1) Temperature of coolant or cylinder head, oil sump, fuel, battery, and battery box interior air temperature.

(2) Battery voltage.

d. After turning off the heater, attempt to start the engine using the techniques of paragraph 4.1.1.b

5. DATA REQUIRED.

5.1 Data Required (Cold Starting without Engine Heater).

a. Temperature of the following, as applicable:

(1) Test chamber.

(2) Engine coolant.

(3) Cylinder head for air-cooled engines, and oil sump for turbine engines.

(4) Fuel.

(5) Engine oil sump.

(6) Battery electrolyte or surface temperature (for sealed batteries).

(7) Induction air.

(8) Transmission sump.

(9) Hydraulic oil reservoir.

(10) Battery box ambient.

(11) Starter.

b. Soak time.

c. Battery voltage and specific gravity before test, with percent of charge.

d. Time from starter engagement to start and for smooth operation (throttle response).

e. Engine cranking speed.

f. Starter cranking voltage and current (data logger record).

g. Number of starting attempts.

h. Fuel pressure.

i. Depending on the engine, should be recording intake air heater current, ether system, glow plugs, or other as applicable.

5.2 Data Required (Cold Starting with Engine Heater).

a. Data as required in paragraph 4.2.

b. Engine preheat time (refer to Figure 4 in section 6 for example).

5.3 Data Required (Engine Heater Standby Test).

a. Standby operating time.

b. Data recorded in paragraph 4.3.1.c.

6. PRESENTATION OF DATA.

Example data presentation curves for component temperature and starter cranking voltage and current versus time are presented in Figure 2. Examples of component performance plots are presented in Figures 3 and 4.

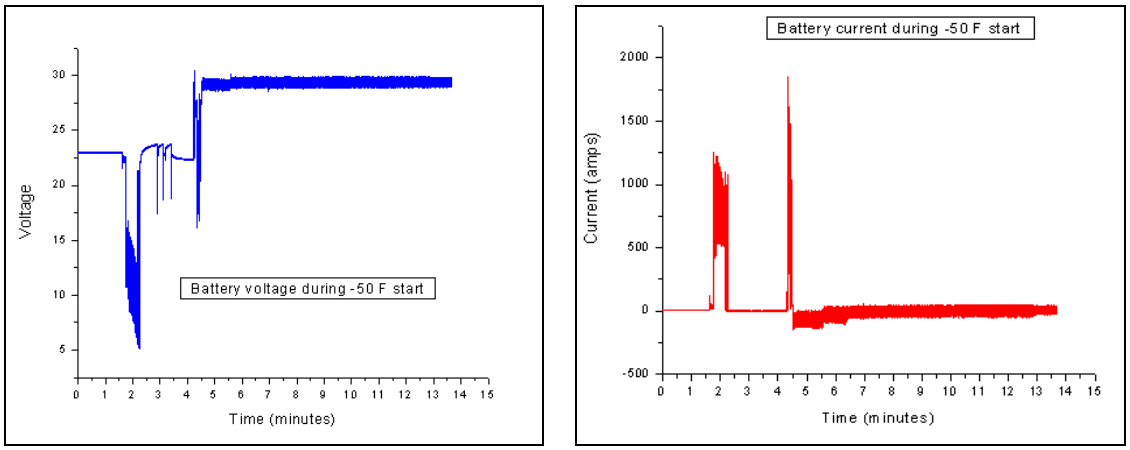

Figure 2. Battery voltage (left) current (right) data collected during -50 F (-46 C) engine start.

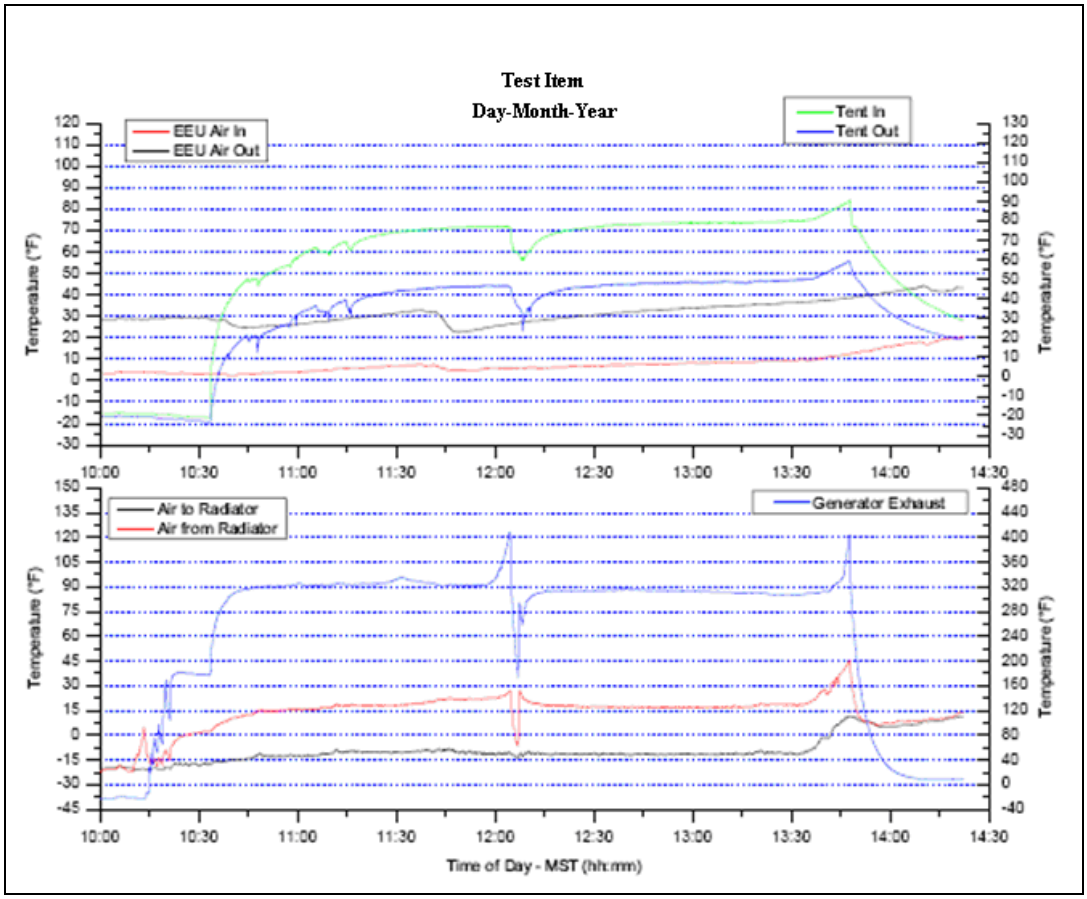

Figure 3. Temperature data during -25 F (-32 C) test.

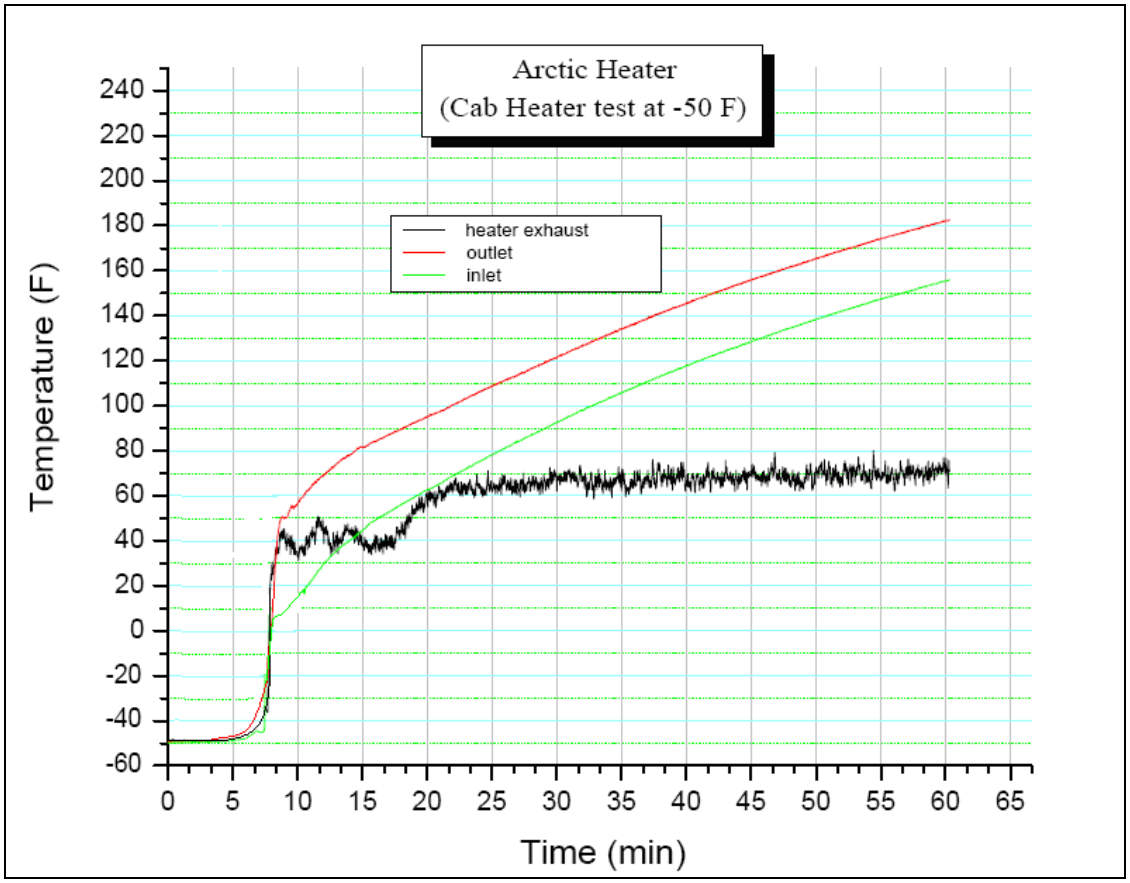

Figure 4. Fluid/exhaust temperature data for an arctic heater prior to -50 F (-46 C) engine start.

APPENDIX A. CHECKLIST GUIDE FOR ENGINE COLD-STARTING TESTS

ITEM	YES	NO	NA
1. Preoperational inspection and services performed on vehicle.			
2. Vehicle prepared for cold-weather operation.			
3. Batteries fully charged.			
4. All required instrumentation calibrated, properly installed, and operational.			
5. Spare batteries on charge.			
6. Means available to slave-start engine if necessary.			
7. Required data recorded.			
8. Safety procedures posted and followed.			
9. Appropriate cold-weather clothing available for test personnel			

APPENDIX B. STARTING TECHNIQUES OF COMPRESSION-IGNITION ENGINES

Use starting aids as required by temperature and engine displacement. Use of ether-like starting fuels is hazardous, and is avoided unless specifically indicated. Ratios of air ether as high as 36:1 by volume are explosive. It is important that only the ether-priming equipment suggested by the engine manufacturer be used and in accordance with the instructions furnished.

With the vehicle transmission in neutral, the clutch disengaged (if a standard transmission), engage the starter. To avoid starter overheating, the cranking period should not exceed 60 seconds unless thermocouples are measuring starter temperature, and the maximum acceptable temperature is known. If a start is not obtained, wait at least 2 minutes before starting the second attempt. During the waiting period fresh electrolyte can come into contact with the battery plates, providing more electrical energy for the second attempt than would otherwise be available.

Use a manifold or airbox heat or priming fuels as necessary to keep the engine running smoothly after starting. Check lubricant and fuel-oil pressure while running. As soon as the engine is running smoothly without aids, reduce to 1200 to 1500 rpm for warmup. Note any unusual results, such as unburned primary fuel in exhaust, detonation, or excessive smoking.

APPENDIX C. STARTING TECHNIQUES FOR TURBINE ENGINES

Starting techniques vary among different turbine engines. Most, however, employ an automatic starting sequence that is electronically controlled. The appropriate operator's manual or technical manual (TM) must be followed during the starting sequence. Operating personnel must be knowledgeable of the hardware characteristics of the item being tested.

With the vehicle transmission in neutral, initiate the starting sequence. Monitor appropriate gauges: voltage, pressure (fuel, oil, etc.), during and after the start attempt. To avoid possible damage to the starter, total continuous cranking time should not exceed 60 seconds, unless the system specification or operator's manual allows a greater cranking period. If a start is not successful, follow procedures necessary to prepare engine for next attempt (this may involve an override procedure to purge the engine of unburned fuel after the second or third start attempt).

Once a start is made, continue operating until all components are at their normal operating temperatures. Continue monitoring all fuel and oil pressures and temperatures during the running cycle. Note any unusual results.

APPENDIX D. REFERENCES

1. Test Operations Procedure (TOP) 2-2-816, High and Low Temperature Tests of Vehicles, 21 March 1979.

2. TOP 2-2-708, Vehicle Personnel Heater Compatibility, 18 July 1980.

3. TOP 2-2-505, Inspection and Preliminary Operation of Vehicles, 04 February 1987.

4. Field Manual (FM) 9-207, Operations and Maintenance of Ordnance Materiel in Cold Weather, 20 March 1998.

5. Technical Manual (TM) 9-6140-200-14, Operator's Unit, Direct Support and General Support Maintenance Manual for Lead-Acid Storage Batteries, 11 September 1998.

6. Army Regulation (AR) 70-38, Research, Development, Test and Evaluation of Materiel for Extreme Climatic Conditions, 15 September 1979.

7. MIL-STD-810F, Department of Defense Test Method Standard for Environmental Engineering Consideration and Laboratory Tests, 1 January 2000.

Forward comments, recommended changes, or any pertinent data which may be of use in improving this publication to the following address: Test Business Management Division (TEDT-TMB), US Army Developmental Test Command, 314 Longs Corner Road Aberdeen Proving Ground, MD 21005-5055. Technical information may be obtained from the preparing activity: Combat and Automotive Systems Division (TEDT-YP-YT), US Army Yuma Test Center, 301 C. Street, Yuma Proving Ground, AZ 85365. Additional copies are available from the Defense Technical Information Center, 8725 John J. Kingman Rd., STE 0944, Fort Belvoir, VA 22060-6218. This document is identified by the accession number (AD No.) printed on the first page.